

*SOME EFFECTS OF INTERTRIAL-INTERVAL
DURATION ON DISCRETE-TRIAL CHOICE*

J. R. JONES AND J. MOORE

UNIVERSITY OF WISCONSIN–MILWAUKEE

Pigeons were trained in Experiment 1 on a discrete-trial concurrent variable-interval (VI) 1-min VI 3-min schedule, and in Experiment 2 on a discrete-trial concurrent VI 1.5-min VI 1.5-min schedule. In each experiment, the intertrial-interval durations (ITIs) were 0 s, 6 s, 22 s, and 120 s, and the schedules were both independent and interdependent. The purpose of the research was to determine whether lengthening the ITI would disrupt any local control that existed, measured with respect to relative response rate and changeover probability. In Experiment 1, with the independent schedules, both preference and obtained relative reinforcement rate approximated .75 at short ITIs, but then decreased toward .50 with longer ITIs. With interdependent schedules, both preference and obtained relative reinforcement rate approximated .75 at all ITIs. In both experiments, with both independent and interdependent schedules, changeover probabilities for each response in a sequence of up to five successive responses to a given schedule were variable for individual birds. The average changeover probabilities for all birds suggested perseveration rather than a systematic increase within a given ITI or a systematic trend toward chance responding as ITI duration increased. Finally, the changeover functions did not differ when a sequence of responses was calculated to begin anew after reinforcement rather than with the first response on a schedule. Taken together, the data were inconsistent with a theory holding that only local processes underlie choice in discrete-trial procedures.

Key words: changeover probability, concurrent variable interval variable interval, molar, molecular, discrete trials, key peck, pigeons

In a seminal investigation, Herrnstein (1961) presented pigeons with a choice between several pairs of concurrently available variable-interval (VI) schedules of reinforcement. He found that the proportion of responding on a schedule approximately equaled, or matched, the proportion of reinforcers obtained on that schedule. Although perhaps not as general as first thought, this relation, known as *matching*, has nevertheless been observed over the years in many settings with many procedural variations (see reviews by Baum, 1979; deVilliers, 1977; Williams, 1988).

One of the central empirical and theoretical questions over the ensuing years is why matching occurs. Two general approaches have become popular. One approach, often

associated with the use of the term *molar*, holds that matching is nothing less than a fundamental property of behavior manifested through the analysis of an organism's behavior across relatively large units of time. The assumption is that the order found at this level of analysis among overall rate of responding, overall time spent responding, overall rate of reinforcement obtained from a schedule, and other molar dimensions of behavior that occur during an experimental session makes an appeal to explanatory phenomena at any other level of analysis unnecessary. In particular, any possible determinants of behavior that occurs at the time of each choice response are to be regarded as incidental, and there should be few if any sequential patterns in the behavior generated on the schedules. In short, this position argues on both theoretical and methodological grounds that a relatively large-scale level of analysis is all that is ever required to adequately explain the distribution of choice responding on concurrent schedules of reinforcement. Although specific details may differ as the approach has evolved, this general sort of approach has been championed by Herrnstein (1961, 1970) and Baum (1981), among others (e.g., see Herrnstein & Vaughan, 1980;

Experiment 1 was carried out in partial fulfillment of the requirements of master of science by the first author under the supervision of the second author. A portion of the data was presented at the conventions of the Association for Behavior Analysis in Atlanta, May, 1991, and the Society for the Quantitative Analyses of Behavior in San Francisco, May, 1996. The first author is now at the University of California–San Diego.

Correspondence concerning this article should be addressed to Jay Moore, Department of Psychology, University of Wisconsin–Milwaukee, Milwaukee, Wisconsin 53201 (E-mail: jcm@csd.uwm.edu).

Mazur, 1981; Vaughan, 1981; for related treatments of the question).

A second theoretical approach as to why subjects match on concurrent schedules, often associated with the use of the term *molecular*, appeals to smaller scale or local processes. One well-known example, advanced by Shimp (1966), is called momentary maximizing. According to this approach, subjects simply choose whichever schedule is associated with the higher probability of reinforcement at the moment of the choice opportunity. This approach is explicitly concerned with temporal variables such as sequences of immediately prior responses, current local probabilities of reinforcement, pauses between responses, and other factors acting at the time of each choice response, rather than overall relations. When matching occurs, it is regarded as an artifact of factors acting at the local level, and therefore as entirely reducible to local factors. Certain procedural variables may obscure this fact and make matching appear to be an emergent property of behavior, but to assume that matching is a fundamental, emergent property of behavior is an error. In any case, momentary maximizing holds that choice on concurrent schedules, whether matching occurs or not, is most appropriately analyzed at the level of individual choice responses to determine the local variables that control behavior (Shimp, 1982; see also Hinson & Staddon, 1983; Silberberg, Hamilton, Zirias, & Casey, 1978).

As suggested in the short review above, one way of distinguishing whether a large- or small-scale approach is more fruitful in the analysis of choice and matching is to determine whether the choice responding manifests any sort of sequential pattern. In brief, if an analysis of the responding does reveal a sequential pattern, then a small-scale approach is supported. If it does not, then a large-scale approach is supported. In an early study following this line of reasoning, Shimp (1966) thoroughly analyzed pigeons' choice behavior at the level of individual responses and argued that the probability of a choice response on a given schedule depended on the immediately preceding sequence of responses and the consequences of those responses. He argued that this sequence served as a cue that indicated the momentary probability of reinforcement on each schedule,

which then guided the distribution of responding.

Another form of sequential analysis concerns the changeover function. This function presents the probability of a changeover at each response in a sequence of successive responses to a given schedule. Following the established convention, the sequence of successive responses to a schedule will be referred to as *run length*. Changeover probability is calculated by dividing the number of times the subject emitted N successive responses on a given schedule by the number of runs of length N or longer (i.e., by the number of times the subject emitted N or more successive responses on that schedule; see Heyman, 1979; Silberberg & Williams, 1974, p. 320, for further details on this method of analysis). In brief, if the slope of the resulting function is positive, then local processes are implicated. If the function is flat, then large-scale processes are all that is necessary to explain the data. For example, Nevin (1969) specifically examined the issues raised by Shimp (1966) and the momentary maximizing hypothesis with regard to patterns of responding and the probability of changing over from one schedule to another as a function of run length. Nevin found matching at the molar level, but the distribution of individual choice responses did not reflect the momentary reinforcement probabilities associated with each schedule. In fact, Nevin (1979) reanalyzed his own earlier data and found that, if anything, there was a slight tendency towards perseveration. Perseveration is the tendency to persist in responding on the same schedule, and is ordinarily manifested as a negative slope to the changeover function. This outcome was exactly opposite that predicted by a molecular account emphasizing momentary maximization. In any event, Nevin concluded that matching was an emergent property of behavior over sessions, and that the momentary probability of reinforcement associated with each schedule on a given trial did not affect individual choice responses.

Subsequently, Heyman (1979) examined the probability of a changeover as a function of run length on three pairs of free-operant concurrent VI VI schedules. As had Nevin (1979), Heyman found an essentially constant probability of a changeover as a function of run length. In fact, his data could be

reasonably well described by a simple Markov process. These data were clearly inconsistent with molecular maximizing and more in keeping with molar approaches.

Finally, Williams (1985) also examined changeover probability in a discrete-trial concurrent VI variable-ratio (VR) schedule with rats as subjects. He observed no correspondence between the probability of a changeover to the VI schedule and the time since the last response to the VI alternative, which was presumably correlated with an increase in the probability of reinforcement associated with the VI alternative. Again, these data do not support an interpretation emphasizing local processes.

However, other studies of changeover probability have found contrasting results. For example, Silberberg and Williams (1974) examined Nevin's (1969) study and cited certain procedural aspects of his research that may account for his findings. Silberberg and Williams noted that Nevin employed a discrete-trial procedure with a formal inter-trial interval (ITI). The ITI procedure consisted of turning off the keylights for a specified interval (e.g., 6 s), a lights-out period, after a response was made. Thus, each choice response represented a discrete trial that was separated from those preceding and following by a lights-out period. If a reinforcer was made available on one of the schedules, a response produced the reinforcer followed by an ITI. If a response was made to a schedule for which a reinforcer was not available, an ITI followed immediately. Responses during the ITI were never reinforced, although the concurrent VI VI schedules continued to time toward reinforcement.

Silberberg and Williams (1974) noted that no experimenter-controlled ITI was explicitly imposed on Shimp's (1966) subjects; those subjects could pause for any duration after each response. Thus, the "relatively longer time [in Nevin's procedure] between successive choices . . . [may have] minimized the conspicuousness of the consequences of different response strategies" (p. 316). In particular, they argued that in Nevin's (1969) study, the ITIs were sufficiently long to interfere with the control exerted by the loci of previous discrete-trial responses, and as a result random errors intruded. Matching was obtained, however, because the subjects were

responding in accord with a momentary maximizing strategy when the contingencies were exerting adequate control, and random errors were evenly distributed over this basic response strategy. However, Silberberg and Williams argued, these random errors obscured the evidence that such a strategy was, indeed, being employed.

In an additional study of the relation between local processes and matching, Silberberg and Zirias (1982) explicitly examined interchangeover times, defined as the time intervals between the first response to one schedule and the first response to the alternative. Their findings, along with similar findings by Hinson and Staddon (1983), suggest that the probability of a changeover increased as time allocated to a given schedule increased: "Times allocated to a schedule are controlled by their local likelihood of reinforcement, and that this correspondence might define the molecular basis of choice" (p. 150). These findings are also in keeping with an approach emphasizing local processes.

One important additional technique remains to be mentioned in conjunction with sequential analyses of choice responding. This technique is linked with studies that have shown that the locus of a prior response can be discriminative for a current response (e.g., Weisman, Dodd, Wasserman, & Larew, 1980), and that sequences of responses are sensitive to reinforcement probabilities (e.g., Fetterman & Stubbs, 1982). The technique in question involves manipulating the duration of the ITI in a discrete-trial choice procedure. The rationale is that if an explanation in terms of local processes is essentially correct, then as the ITI increases, the locus, and possibly the outcome, of prior responses will be less likely to be discriminative for the current response. If so, then perhaps the overall distribution of choice responses and certainly the changeover functions with short ITIs should differ from those with long ITIs.

In fact, Silberberg and Williams (1974) used just this procedure. They trained pigeons on a discrete-trial probability learning procedure in which responses to either of two keys incremented the probability that the first changeover response to the other key would be reinforced. Responses on one of the keys incremented this probability faster than re-

sponses on the other. Changeover responses provided the only opportunity for reinforcement, but also reset the probability of reinforcement for continued responding on a key to zero. A parallel to responding on concurrent VI VI schedules may be seen: As time is spent responding on one VI schedule, the probability of reinforcement on other schedule, and consequently the probability of reinforcement for changing over, increases accordingly. Each of three pairs of birds received ITIs of different duration: 1, 22, or 120 s. Silberberg and Williams argued that if momentary maximizing was the strategy employed in all choice responding, which under most conditions leads to matching, then this procedure should produce a response pattern of alternating between keys. They did find an increasing tendency toward alternation between keys, but with longer ITIs more sessions were required for this pattern to develop. The subjects exposed to 1-s ITIs began to alternate between keys within 20 sessions. The subjects exposed to 22-s ITIs initially tended toward matching, then subsequently developed a tendency to alternate responses. For the 120-s ITI condition, subjects initially responded exclusively to one key or the other. These subjects eventually matched after further exposure to the schedule, but after 100 sessions these subjects only developed a minor tendency to alternate responses between alternatives. Silberberg and Williams concluded that the subjects exposed to the 1-s ITIs unambiguously demonstrated "that momentary maximizing was the concurrent response rule defining their choice allocations" (p. 320). Subjects exposed to longer ITIs, as in Nevin's (1969) study, did not as clearly demonstrate a response pattern based upon momentary maximizing. In such cases momentary maximizing might still motivate choice, but the loci of the last few responses exert control only infrequently.

More recently, Williams (1983, 1991, 1992) manipulated ITI duration to further study how longer ITIs affected discrete-trial choice responding. Williams (1983, 1991) trained subjects (pigeons in the first study, rats in the second) on a discrete-trial probability learning procedure in which the local contingencies of reinforcement differentially reinforced a win-stay, lose-shift response pattern. He found that the win-stay portion was

learned earlier, and prevailed under longer ITIs, than the lose-shift pattern. He also noted that the local reinforcement contingencies were discriminated poorly with longer ITIs. Overall, he suggested that choice was determined by both molar and local contingencies.

Williams (1992) then followed up the earlier studies by training rats on a discrete-trial version of a concurrent VI VR schedule with both short (5-s) and long (30-s) ITIs. He found that the pattern of choice was strongly affected by ITI duration. With the 5-s ITI he found evidence of both a bias in favor of the VR alternative and some discrimination of local contingencies of reinforcement, as revealed in an increasing probability to choose the VI alternative as a function of the number of trials since the last VI choice (his Figure 4). With the 30-s ITI, he found less bias and no discriminative effect of the locus of the response on the preceding trial. Thus, both the bias and discrimination of the local contingencies depended on trial-by-trial dynamics that did not operate with longer ITIs. As in his earlier research, Williams concluded that the two sources of control are independent; that is, neither is reducible to the other. He interpreted matching as the result of the interaction between both long-term molar processes and short-term local processes. When placed in competition, short-term molecular processes will prove the stronger of the two, but longer term molar processes will still be evident.

Taken together, then, the results of past experimental analyses of changeover patterns are mixed. Some studies have found that as the time allocated to an alternative increases, changeover probability fails to increase, remaining constant (Heyman, 1979) or perhaps even decreasing slightly (Nevin, 1969, 1979). Other choice studies have found that as the time allocated to an alternative increases, changeover probability does increase (Shimp, 1966; Silberberg et al., 1978; see also Hinson & Staddon, 1983). In addition, the data from manipulations of ITI duration on discrete-trial choice procedures suggest that local processes do operate (Williams, 1992; see also Mohr, 1976), but further research using this technique seems warranted, particularly because Shimp's (1966) interpretation of the relation between local and molar processes

(i.e., that molar processes are entirely reducible to local processes) differs from Williams' (1992) interpretation (i.e., that both local and molar processes exist, and that molar processes are not reducible to local).

The purpose of the present two experiments was to examine choice in a discrete-trial concurrent VI VI procedure with parametrically increasing ITIs. As in Silberberg and Williams (1974) and Williams (1992), the rationale for this manipulation was to determine whether lengthening the ITI would disrupt any local control that existed. Experiment 1 employed unequal concurrent VI VI schedules, and Experiment 2 employed equal concurrent VI VI schedules. In addition, in each experiment, reinforcement was arranged according to both independent and interdependent schedules. At issue was whether the data from independent schedules differed from those of interdependent schedules. Interdependent schedules (e.g., Stubbs & Pliskoff, 1969) have sometimes been controversial. Some critics have argued that they actually bias the behavior by forcing the subject to respond more to the alternative schedule than it would without the arrangement. If so, then changeover probabilities should be higher with interdependent than independent schedules.

The overall relation between response and reinforcer distribution was examined with independent and interdependent schedules to determine how the two measures would be affected by the increases in ITI. The data from Experiment 1, with unequal schedules, were presumably more relevant to addressing this issue than those from Experiment 2, with equal schedules. For example, in Experiment 1 a possibility is that relative response rate would tend toward .50 at the longer ITIs, because the long ITI would disrupt whatever organization existed, and behavior would simply revert to chance.

The changeover probability was examined to determine whether the function relating changeover probability to successive responses changed systematically, both within a given ITI and across the increasing ITIs. Data from both experiments were relevant to addressing this issue. As noted above, a focal concern since at least the 1970s is whether the slope of the changeover function is flat (i.e., zero) or positive. For example, one possibility in

the present research, derived from molecular theories, is that the slope of the function will be positive at short ITIs and then will revert to being flat with longer ITIs (e.g., Williams, 1992). This pattern should be evident with both unequal and equal schedules. The short ITIs allow control by the locus of the response on the preceding trial, whereas the longer ITIs disrupt the control, such that responding successively tends toward randomness, evidenced by a flat slope with a changeover probability at chance values, or .50. Finally, the changeover probabilities were analyzed in two different ways. In the first way, which is the standard way, the sequence of responses was considered to begin with the first response to a given schedule after a changeover from the other schedule. The sequence was considered to end with the first response to the other schedule. These analyses are designated as "overall." In the second way, which had not previously been examined, the sequence of responses was considered to begin with either (a) the first response to a given schedule after a changeover from the other schedule or (b) the first response after a reinforcer on a schedule, even if the response was on the same schedule as the response that had produced the reinforcer. The sequence was considered to end with either (a) the first response to the other schedule or (b) the next reinforcer on the same schedule. These analyses are designated as "post," as in postreinforcement. At issue was whether a finer grained postreinforcement level of analysis would yield different data than an overall level of analysis, given that the occurrence of a reinforcer is likely to be a salient event for animals.

GENERAL METHOD

Subjects

Altogether, 12 pigeons served in the research. Six pigeons (B-3547, B-647, B-616, B-16, B-4625, and B-22) served in Experiment 1, and 6 pigeons (R-1, R-5, R-6, R-7, R-8, and R-9) served in Experiment 2. The birds were male, of mixed breeds and varying ages. The birds in Experiment 1 were naive at the start of the research, whereas those in Experiment 2 had 6 to 12 months of exposure to various single-key VI schedules of reinforcement. The

birds were maintained at approximately 80% of their free-feeding body weights. The birds were housed in individual cages, in a continuously lighted room, with continuous access to water. Sessions were conducted at approximately the same time of day, 5 to 6 days per week.

Apparatus

The two experiments used three three-key experimental chambers for pigeons. The interior dimensions of the chambers were approximately 28 cm (height) by 30 cm (width) by 36 cm (depth). On the front wall of each chamber were three circular response keys (2.5 cm in diameter) and a rectangular opening (5 cm by 6 cm) that provided access to an elevated food hopper. The keys were mounted 22 cm above the floor. The center response key was centered on the wall, and the two side keys were 11 cm to the left and right of the center key. The keys required approximately 0.15 N to operate. The keys could be illuminated from the rear with red, green, or white lights by means of a standard IEEE projector with 28-VDC lightbulbs (1820, 3 W). The rectangular opening to the food hopper was also centered on the wall, 5 cm above the floor. An Apple 2e® computer, located in an adjacent room, controlled experimental events and recorded the data for each chamber.

Procedure

The birds were first given any necessary preliminary training. They were then trained on the respective concurrent VI VI schedules (in Experiment 1, concurrent VI 1 min VI 3 min; in Experiment 2, concurrent VI 1.5 min VI 1.5 min) under a conventional free-operant procedure. Then they were trained on the discrete-trial procedure.

In the current discrete-trial procedure, the center key was the main response key. The two side keys were changeover keys. At the start of a session and during an ITI, all three keys were dark. When a trial began, the center key was white, one side key was red, and the other was green. The locations of red and green on the side keys were reversed every 10 trials within a session. Four consecutive responses to the red side key changed its color to white, darkened the other side key, and brought VI Schedule A into effect on the cen-

ter key, signified by a change in the color of the center key from white to red. Analogous events occurred after four consecutive responses to the green side key, except that VI Schedule B came into effect. Further responding on the now white side key had no consequence. If the interreinforcement interval had not elapsed on the VI schedule that was brought into effect, a single peck on the colored center key resulted in the immediate return to the ITI, as indicated by the three dark keys. If the interreinforcement interval had elapsed on the VI schedule that was brought into effect, a single peck on the colored center key produced 3-s access to the illuminated food hopper. After the reinforcement cycle, the ITI began, as indicated by the three dark keys. All birds responded readily in all conditions. Consequently, terminating trials if the bird failed to respond within some specified time interval did not prove to be necessary (cf. Nevin, 1969). As noted below, in Experiment 1, VI Schedule A (correlated with a red key color) was VI 1 min, and VI Schedule B (correlated with a green key color) was VI 3 min. In Experiment 2, both Schedules A and B were VI 1.5 min. All schedules had 10 interreinforcement intervals, derived from the equation of Catania and Reynolds (1968, p. 381). The order of the intervals differed in each session.

Experimental variables. The experiments employed four ITI durations, taken from prior research as follows: 0 s (Shimp, 1966), 6 s (Nevin, 1969), 22 s (Silberberg & Williams, 1974), and 120 s (Silberberg & Williams, 1974). These ITIs are also in keeping with the 5-s and 30-s ITIs employed by Williams (1992). In addition, the concurrent VI VI schedules were either independent or interdependent. With independent schedules, a schedule timed toward reinforcement at all times during the procedure except when the reinforcer was (a) available on the schedule or (b) actually being presented. Thus, timing toward reinforcement on one schedule was independent of the availability of reinforcement on the other. With interdependent schedules, a schedule timed toward reinforcement except when the reinforcer was (a) available on the schedule, (b) actually being presented, or (c) available on the other schedule. Timing in this third case resumed only after the reinforcer had been collected

Table 1

The order of conditions and number of sessions for each bird in Experiment 1. The order is shown before the parentheses in each cell, and the number of sessions follows within the parentheses. The duration of the intertrial interval (ITI) is specified in seconds, and the schedule type is either independent (ind) or interdependent (int).

ITI and schedule type	Bird					
	B-3547	B-647	B-616	B-16	B-4625	B-22
0 s, ind	1 (14)	1 (10)	1 (14)	1 (18)	1 (20)	1 (16)
0 s, int	8 (10)	5 (13)	8 (11)	5 (19)	8 (9)	5 (13)
6 s, ind	3 (9)	2 (10)	4 (13)	6 (23)	3 (9)	8 (13)
6 s, int	5 (9)	6 (11)	2 (16)	4 (12)	6 (17)	7 (15)
22 s, ind	7 (11)	3 (11)	6 (18)	3 (9)	2 (16)	6 (11)
22 s, int	6 (12)	7 (12)	3 (9)	2 (10)	4 (9)	3 (9)
120 s, ind	4 (10)	4 (24)	5 (22)	7 (10)	7 (10)	2 (31)
120 s, int	2 (16)	8 (10)	7 (17)	8 (15)	5 (20)	4 (12)

on the other schedule (cf. Stubbs & Pliskoff, 1969). Overall, each experiment consisted of eight conditions in a 4×2 (ITI duration \times schedule type) design. Each bird was trained first on the 0-s ITI independent schedule, and then was trained on each of the remaining seven conditions in a random order (except for B-647 in Experiment 1, as noted in Table 1).

Session length. A session was considered complete if 40 reinforcers had been delivered. In the majority of sessions, 40 reinforcers were delivered within 2 hr. If 40 reinforcers were not obtained within 2 hr, for example, with long ITIs and interdependent schedules, sessions were terminated manually after at least 15 reinforcers had been obtained.

Stability criterion. A bird was exposed to a particular experimental condition until its behavior satisfied a stability criterion. A minimum of nine sessions on a given condition was required. For the last nine sessions the relative response rates when a given schedule was in effect on the center key [$\text{resp}_A / (\text{resp}_A + \text{resp}_B)$] were calculated and averaged over three blocks of three sessions each. If the means of the three blocks did not evidence either a monotonically increasing or decreasing trend and the difference between highest and lowest mean did not exceed .05, behavior was considered stable. The bird was then trained on the next experimental condition. No upper limit on the number of sessions to

which a bird was exposed in a given condition proved to be necessary.

Dependent measures. The overall numbers of responses and reinforcers were recorded for each schedule, as in standard concurrent-schedule research. In addition, the sequences of responses and reinforcers from the last three sessions of each condition were pooled and analyzed to determine the probability of a changeover as a function of each response in a sequence of successive responses, or run length. Run length in the changeover data was calculated in two ways: an overall level of analysis and a postreinforcement level of analysis. In each way, the probability of a changeover was calculated for each response on a run for run lengths of up to five responses, given that there were at least two instances of a run consisting of the specified number of responses. This criterion was occasionally not met with runs of three, four, or five responses on the interdependent schedules in the postreinforcement analysis, as shown in Tables 2 and 4. The rationale for the limitation was that a meaningful analysis should presumably be based on more than just a single instance of responding.

EXPERIMENT 1: CONCURRENT VI 1 MIN VI 3 MIN

METHOD

Subjects and Procedure

Birds B-3547, B-647, B-616, B-16, B-4625, and B-22 served as subjects.

As described above, a discrete-trial version of a concurrent VI 1-min VI 3-min schedule was employed. All subjects received each of the four ITI conditions (0 s, 6 s, 22 s, 120 s) combined with the two schedule types (independent and interdependent) to make a total of eight conditions. The order of training for the birds in the eight conditions is indicated in Table 1. Each subject was trained first on the independent 0-s ITI condition, followed by randomly ordered presentations of the other seven conditions, except for B-647, which was first trained on all four independent conditions and then on all four interdependent conditions in order of increasing ITI duration.

Table 2

Changeover probabilities for runs of up to five responses for each bird in Experiment 1. The data include the duration of the ITI (in seconds), whether the schedules were independent (ind) or interdependent (int), whether the level of analysis was based on runs calculated on an overall basis or postreinforcement, the relative response and reinforcement rates (expressed in terms of the VI 1-min schedule), and the changeover probabilities. In Experiment 1, the A schedule is the VI 1-min schedule, and the B schedule is the VI 3-min schedule.

Bird	ITI	Schedule type	Level of analysis	Relative rate		Changeover probability									
				Re-spon-ses	Rein-forcement	A → B					B → A				
						1	2	3	4	5	1	2	3	4	5
B-3547	0 s	Ind	Overall	.82	.78	.26	.32	.27	.15	.21	.78	.81	.88		
		Ind	Post			.45	.20	.08	.06	.04	.48	.69			
		Int	Overall	.71	.75	.38	.46	.46	.35	.41	.96				
		Int	Post			.19	.54	.50	.58	.50	1.0				
	6 s	Ind	Overall	.76	.75	.26	.22	.20	.17	.27	.77	.87	.25	0	.33
		Ind	Post			.37	.31	.26	.22	.36	.57	.77	.33	0	
		Int	Overall	.75	.75	.25	.19	.24	.35	.36	.90	.94			
		Int	Post			.27	.28	.32	.38	.58	.87	.75			
	22 s	Ind	Overall	.65	.70	.43	.29	.35	.18	.22	.70	.68	.75		
		Ind	Post			.41	.26	.26	.43	.17	.68	.73	0	0	
		Int	Overall	.79	.75	.23	.28	.26	.11	.32	.89	.78			
		Int	Post			.20	.14	.27	.28	.36	.93				
	120 s	Ind	Overall	.66	.67	.39	.35	.18	.33	.17	.62	.82			
		Ind	Post			.37	.29	0			.70	.71			
		Int	Overall	.70	.75	.39	.32	.19	.19	.11	.67	.52	.67	.40	.83
		Int	Post			.33	.21	.36	.13	.14	.77	.43			
B-647	0 s	Ind	Overall	.78	.77	.25	.28	.31	.39	.20	.83	.74	.67	.33	0
		Ind	Post			.31	.22	.29	.23	.07	.41	.76	.25	0	0
		Int	Overall	.70	.75	.35	.42	.41	.41	.30	.90				
		Int	Post			.44	.29	.27	.29	.20	.57				
	6 s	Ind	Overall	.72	.76	.42	.24	.29	.22	.14	.68	.55	.29	.17	.10
		Ind	Post			.39	.19	.11	.10	.12	.50	.47	.38	.25	0
		Int	Overall	.67	.75	.47	.50	.32	.43	.30	.87	.79			
		Int	Post			.35	.47	.42	.17	.25	.63	.91			
	22 s	Ind	Overall	.63	.72	.48	.36	.10	.32	.23	.48	.52	.44	.22	.57
		Ind	Post			.41	.16	.10	.11	.08	.52	.38	.33	.50	
		Int	Overall	.73	.75	.35	.34	.30	.19	.27	.74	.75	.71		
		Int	Post			.34	.26	.25	.22	.15	.60	.83	.50		
	120 s	Ind	Overall	.52	.58	.45	.39	.43	0	.25	.44	.33	.44	.44	.60
		Ind	Post			.43	.32				.50	.32	.44	.33	0
		Int	Overall	.69	.75	.39	.22	.50	.22	.14	.66	.62	.20	.50	
		Int	Post			.32	.25	.25	.20	.25	.53	.71	0	.50	
B-616	0 s	Ind	Overall	.69	.75	.37	.44	.36	.29	.22	.84	.80	.44	.40	.33
		Ind	Post			.56	.41	.35	.23	.30	.43	.88			
		Int	Overall	.66	.75	.41	.56	.58	.27	.33	.95	.81	.33	.50	
		Int	Post			.35	.44	.46	.33	.14	.83	.80			
	6 s	Ind	Overall	.64	.73	.46	.44	.49	.43	.50	.83	.78	.86		
		Ind	Post			.52	.43	.59	.29	.80	.52	.69	.80		
		Int	Overall	.76	.75	.19	.28	.28	.33	.43	.93	.82	.50		
		Int	Post			.20	.22	.31	.25	.33	.83				
	22 s	Ind	Overall	.69	.71	.37	.42	.33	.30	.21	.78	.72			
		Ind	Post			.36	.30	.40	.29		.83	.83			
		Int	Overall	.75	.75	.33	.26	.18	.27	.26	.80	.83	.33	0	.5
		Int	Post			.30	.25	.30	.20	.13	.83	.60	.50		
	120 s	Ind	Overall	.55	.59	.49	.15	.29	.33	.25	.44	.32	.47	.50	.25
		Ind	Post			.43	.22	.25			.39	.39	.56		
		Int	Overall	.69	.77	.35	.30	.30	.26	.29	.69	.64	.38	.20	.50
		Int	Post			.31	.25	.20	.18	.56	.70	.56	.75		

Table 2
(Continued)

Bird	ITI	Sched- ule type	Level of analysis	Relative rate		Changeover probability									
				Re- spon- ses	Rein- force- ment	A → B					B → A				
						1	2	3	4	5	1	2	3	4	5
B-16	0 s	Ind	Overall	.72	.75	.35	.37	.34	.25	.23	.82	.92			
		Ind	Post			.48	.22	.34	.44	.22	.43	.94			
		Int	Overall	.64	.75	.47	.58	.64	.42	.53	.90	.90	.5	.5	
	6 s	Ind	Post			.34	.48	.70	.71	.50	.80	.83			
		Ind	Overall	.68	.74	.39	.47	.44	.50	.50	.84	.86			
		Ind	Post			.18	.47	.59	.55	.60	.81	.83			
	22 s	Int	Overall	.74	.75	.28	.26	.28	.22	.21	.79	.74	.57	.67	
		Int	Post			.20	.20	.21	.21	.28	.70	.71			
		Ind	Overall	.74	.75	.27	.32	.41	.26	.29	.77	.50	.67		
	120 s	Ind	Post			.25	.24	.34	.25	.33	.68	.40	.67		
		Int	Overall	.69	.75	.40	.38	.26	.35	.25	.64	.66	.64	.40	
		Int	Post			.33	.38	.24	.25	.33	.63	.82	0		
		Ind	Overall	.67	.67	.38	.48	.29	.58	.60	.77	.83	.50		
		Ind	Post			.35	.48	.25			.71	.92			
		Int	Overall	.68	.75	.27	.30	.39	.16	.25	.58	.60	.40	0	.50
		Int	Post			.26	.26	.27	.14	.33	.54	.73	.67		
B-4625	0 s	Ind	Overall	.67	.74	.50	.51	.42	.43	.35	.86	.85	.80		
		Ind	Post			.38	.43	.29	.31	.36	.77	.86			
		Int	Overall	.68	.75	.34	.50	.47	.44	.41	.93	.94			
	6 s	Ind	Post			.27	.50	.57	.10	.13	.83				
		Ind	Overall	.70	.74	.41	.37	.30	.30	.21	.80	.72	.71		
		Ind	Post			.50	.30	.30	.19	.27	.61	.75			
	22 s	Int	Overall	.68	.75	.37	.47	.49	.54	.63	.87	.81			
		Int	Post			.46	.42	.61	.71	0	.83	.80			
		Ind	Overall	.55	.69	.59	.47	.40	.33	.13	.51	.56	.55	.56	.50
	120 s	Ind	Post			.48	.30	.32	.36	.20	.53	.65	.50	.67	
		Int	Overall	.67	.75	.35	.39	.30	.56	.36	.72	.81	.33	.75	
		Int	Post			.44	.36	.37	.60	0	.70	.44	.50		
		Ind	Overall	.63	.67	.51	.48	.36	0	.14	.70	.38	.63	0	.67
		Ind	Post			.35	.23				.64	.36	.67		
		Int	Overall	.64	.75	.39	.30	.39	.29	.20	.69	.65	.17	.80	
		Int	Post			.30	.27	.23	.38	.20	.67	.50	.50		
B-22	0 s	Ind	Overall	.78	.75	.24	.42	.34	.18	.19	.87	.68	.55	.40	.33
		Ind	Post			.36	.48	.26	.24	0	.57	.75	.67		
		Int	Overall	.68	.75	.55	.40	.44	.42	.43	.97				
	6 s	Ind	Post			.33	.43	.38	.17	.29	.63				
		Ind	Overall	.72	.74	.41	.38	.27	.38	.28	.83	.76	.83		
		Ind	Post			.41	.27	.23	.45	.18	.52	.87			
	22 s	Int	Overall	.74	.75	.32	.34	.31	.35	.20	.76	.75	.67	.33	.5
		Int	Post			.44	.19	.21	.22	.15	.72				
		Ind	Overall	.68	.71	.43	.39	.29	.30	.29	.74	.67	.86		
	120 s	Ind	Post			.31	.38	.15	.44	0	.69	.55			
		Int	Overall	.68	.75	.34	.33	.30	.35	.30	.63	.59	.87		
		Int	Post			.27	.27	.25	.33	.45	.73	.63			
		Ind	Overall	.57	.62	.42	.32	.33	.30	.43	.45	.19	.47	.22	.57
		Ind	Post			.31	.25	.33			.38	.25	.54		
		Int	Overall	.63	.73	.47	.38	.32	.35	.27	.58	.78	.86		
		Int	Post			.39	.36	.27	0	0	.55	.77			

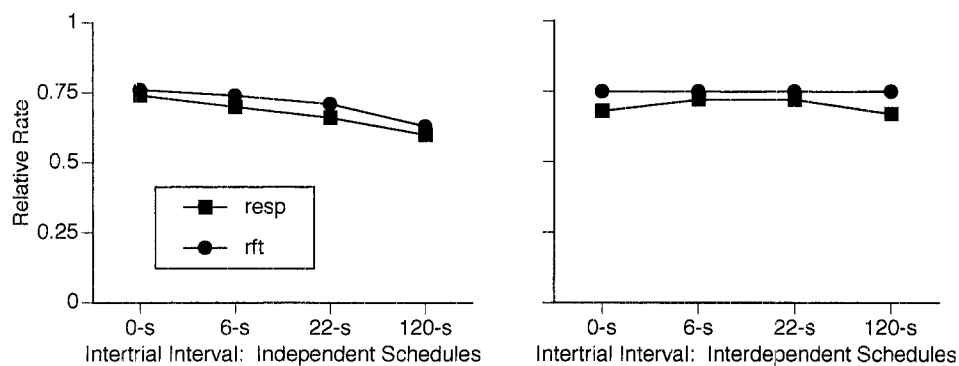


Fig. 1. Average relative response and reinforcement rates in Experiment 1.

RESULTS AND DISCUSSION

Figure 1 presents the average relative response and reinforcement rates in Experiment 1, taken from the data of individual subjects in Table 2. These data are presented as a function of ITI duration, and are expressed in terms of the VI 1-min schedule. The left panel of Figure 1 indicates that relative response rate decreased from approximately .75 toward .50 as the ITI increased from 0 s to 120 s. Inspection of the data in Table 2 indicates that relative response rate decreased steadily for some subjects as a function of ITI, whereas it decreased more variably, with a large decrease between ITIs of 22 s and 120 s, for other subjects. In addition,

obtained relative reinforcement rate approximated the scheduled rate of .75 with relatively short ITIs of 0 and 6 s, and then decreased toward .50 with the longer ITIs of 22 and 120 s. Finally, the subjects exhibited some degree of undermatching throughout, in which relative response rate was lower than obtained relative reinforcement rate, but there was no systematic increase or decrease in the magnitude of the undermatching as the ITI increased. The data may legitimately be called undermatching, rather than simply bias, owing to the reversal of the position of the keys during each session.

The right panel of Figure 1 indicates that relative response rate remained relatively sta-

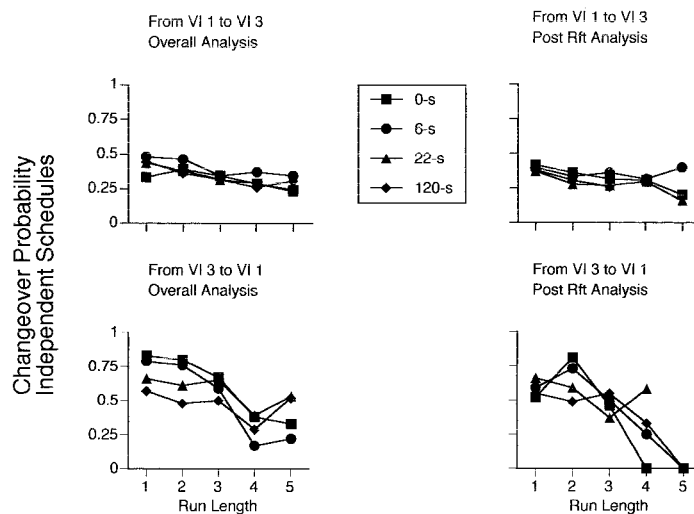


Fig. 2. Average changeover probabilities as a function of run length for independent schedules in Experiment 1.

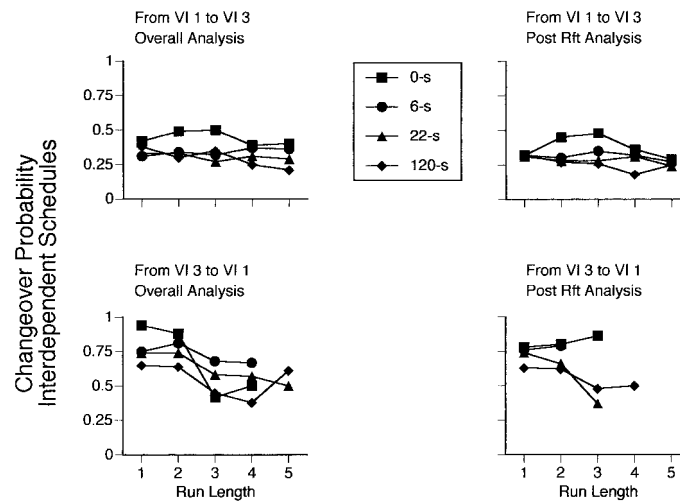


Fig. 3. Average changeover probabilities as a function of run length for interdependent schedules in Experiment 1.

ble at .75 for the interdependent schedules, without showing any systematic decrease toward .50 as ITI duration increased. This result may be contrasted with the decrease in relative response rate toward .50 for the independent schedules. Obtained relative reinforcement rate for the interdependent schedules remained approximately at .75. Finally, some degree of undermatching occurred throughout, in that relative response rate was lower than obtained relative reinforcement rate. However, there was no systematic increase or decrease in the magnitude of the undermatching as the ITI increased.

Figure 2 presents the average changeover probabilities in Experiment 1 for the four ITI durations with independent schedules, again taken from the data of individual subjects in Table 2. The data are presented as a function of runs up to five responses for both the overall and postreinforcement analyses. The data in the upper panels indicate that the probability of changing over from VI 1 min to VI 3 min after one or two responses of a run was generally below .50 and then decreased slightly as run length increased. The data from the postreinforcement level of analysis do not differ systematically from those from the overall level of analysis. The data in the lower panels are more variable. The probability of a changeover early in the visit to the

VI 3-min schedule was higher, as would be expected with the minority schedule, but then it decreased noticeably for run lengths of four and five for both overall and postreinforcement analyses.

In Figure 3, the data are generally consistent with those of Figure 2, with the exception that the absolute probability of a changeover was higher at the various runs of length N . For example, this difference is apparent when the lower right panel of Figure 2 is compared with that of Figure 3.

Overall, with the occasional exceptions noted, the average data of Experiment 1 suggest some perseveration as run length and ITIs increased, rather than either (a) a systematic increase in changeover probability within any ITI or (b) a slope that was initially positive and then systematically approached zero with longer ITIs. Inspection of the individual data in Table 2 indicates considerable variability in the various conditions of the experiment, both within and between subjects. Although the performance of the individual subjects is not always reflected in the group average, Figures 2 and 3 and Table 2 nevertheless do not suggest that the momentary probability of reinforcement exerted control over preference at short ITIs, as would have been reflected in an increasing changeover probability as a function of run length.

Table 3

The order of conditions and number of sessions for each bird in Experiment 2. The order of the condition precedes the parentheses, and number of sessions follows within the parentheses. The duration of the intertrial interval (ITI) is specified in seconds, and the schedule type is either independent (ind) or interdependent (int).

ITI and schedule type	Bird					
	R-1	R-5	R-6	R-7	R-8	R-9
0 s, ind	5 (9)	5 (9)	3 (9)	2 (9)	7 (10)	5 (26)
0 s, int	1 (14)	1 (11)	1 (15)	1 (12)	1 (11)	1 (10)
6 s, ind	7 (9)	2 (11)	2 (10)	7 (19)	8 (9)	7 (15)
6 s, int	2 (10)	8 (9)	6 (9)	3 (10)	6 (11)	6 (23)
22 s, ind	3 (12)	7 (10)	8 (9)	5 (9)	2 (11)	8 (11)
22 s, int	4 (11)	4 (19)	5 (10)	8 (10)	3 (11)	4 (10)
120 s, ind	2 (16)	3 (11)	4 (9)	4 (17)	4 (12)	3 (10)
120 s, int	8 (9)	6 (9)	7 (10)	6 (23)	5 (19)	2 (24)

EXPERIMENT 2: CONCURRENT VI 1.5 MIN VI 1.5 MIN

METHOD

Subjects and Procedure

Birds R-1, R-5, R-6, R-7, R-8, and R-9 served as subjects.

As described above, a discrete-trial version of concurrent VI 1.5 min VI 1.5 min was employed. The order of training for the birds in the eight conditions is indicated in Table 3.

RESULTS AND DISCUSSION

The data from Experiment 2 are presented in Table 4 and Figures 4, 5, and 6. The table, figures, and general presentation of the results for Experiment 2 parallel those for Experiment 1. To avoid confusion, one VI 1.5-min schedule will be designated A, and the other will be designated B. Table 4 presents the schedule type (independent or interdependent), level of analysis (overall or postreinforcement), relative response and reinforcement rates, and changeover data for responses on runs of up to five responses at each ITI duration for each bird, again with the same limitation as in Experiment 1, namely, that there had to be at least two runs of the specified length for changeover data to be included in the analysis. The changeover data for R-5 with independent schedules at the postreinforcement level of analysis were inadvertently lost while copying a computer file and are not available.

Figure 4 presents the average relative response and reinforcement rates in Experiment 2, taken from the data of individual subjects in Table 4. The data are presented as a function of ITI duration, and are expressed in terms of the A schedule. The relative response and reinforcement data are presented here for completeness, even though they are not critical to any particular theoretical argument. The schedules on each key were identical and were not expected to generate differential responding. Figure 4 indicates that relative response rate approximated .50 at each ITI, as was expected. In addition, obtained relative reinforcement rate approximated the scheduled rate of .50 at each ITI. Finally, relative response rate matched obtained relative reinforcement rate throughout.

Figure 5 presents the average changeover probabilities in Experiment 2 for the four ITI durations with independent schedules, taken from the data of individual subjects in Table 4. The data are presented for each response on runs up to five responses on each schedule for both the overall and postreinforcement analyses. Figure 6 presents comparable data when the schedules were interdependent. Recall that Experiment 2 was designed to determine whether the data obtained when equal scheduled relative reinforcement rates were employed yielded different conclusions about changeover patterns than did the data obtained when unequal scheduled relative reinforcement rates were employed.

As in Figures 2 and 3 from Experiment 1, the data in Figures 5 and 6 are generally quite variable, but they do not indicate that the changeover probability increased systematically within a given ITI, or even that it decreased systematically to a chance probability of .50 as ITIs increased. On average, the effect that does seem to be present is that the changeover probabilities after one and two responses with 0-s and 6-s ITIs approximated .75, whereas those after one and two responses with 22-s and 120-s ITIs tended more toward .50. Changeover probabilities after three, four, and five responses with all ITIs tended to be variable, but were closer to .50. In addition, the range of changeover probabilities at each run length tended to be greater with independent schedules than with interdependent schedules. With regard to

trends within an ITI, if anything, the average changeover probabilities in all conditions were often lower rather than higher after four or five responses to a given schedule, suggesting perseveration rather than a general pattern of maximizing based on the momentary probability of reinforcement. Overall, the changeover patterns of Experiment 2, with equal scheduled relative reinforcement rates, are in keeping with those of Experiment 1, with unequal scheduled relative reinforcement rates, and show no systematic evidence that a local variable such as momentary probability of reinforcement controlled the location of responding.

GENERAL DISCUSSION

These two experiments examined the effects on choice of parametrically increasing the ITI in a discrete-trial concurrent VI VI procedure. At issue was whether longer ITIs would disrupt any control exerted by local contingencies, measured with respect to overall response distributions and changeover patterns. Behavior was examined when the scheduled relative reinforcement rates were unequal as well as equal, and with independent as well as interdependent schedules. In addition, changeover patterns were analyzed at an overall level as well as beginning immediately after reinforcement.

As shown in Figure 1, the choice data in Experiment 1 for independent schedules indicated that although there was a slight but constant degree of undermatching throughout, relative response and obtained relative reinforcement rates decreased from .75 at short ITIs toward .50 with longer ITIs. For interdependent schedules in Experiment 1, the relative reinforcement rate was fixed at .75, and relative response rate remained closer to .75 than for independent schedules across the full range of ITIs.

At issue is why the relative response rate tended toward .50 as ITI increased with independent but not interdependent schedules. If the locus of the last response exerts discriminative control, and if lengthening the time since the last response can ordinarily be expected to reduce that control, one might expect responding to drift toward .50 just as much with interdependent as with independent schedules, because the same period of

time was interposed between successive responses on each schedule type.

The answer presumably lies in an analysis of the way that relative reinforcement probability changed as the ITI increased with independent but not interdependent schedules. For simplicity, a constant-probability aperiodic schedule may be defined in the technical terms of a random-interval schedule, and the conventions of Millenson (1963; see also the discussion in Catania & Reynolds, 1968, Appendix II) are employed below to analyze the temporal dynamics of the schedules. These schedules consist of two parameters: a time period (Δt) after which reinforcement is made available according to a specified probability (p). The mean interreinforcement interval of the schedule is then given by $\Delta t/p$. For example, a VI 1-min schedule might be described as having a Δt of 3 s and a probability of .05: $3 \text{ s}/.05 = 60 \text{ s}$. Similarly, a VI 3-min schedule might be described as also having a Δt of 3 s and a probability of .017: $3 \text{ s}/.017 = 180 \text{ s}$.

The formula for computing the probability that reinforcement has become available when several Δt periods have passed without a response on the schedule, as they would during an ITI, is derived from the binomial theorem: $P = 1 - q^n$. In this formula, P is the probability that reinforcement is available, q is 1 minus the probability of reinforcement after the Δt period on the schedule, and n is the number of Δt periods that have passed without a response on the schedule (e.g., during the ITI).

Solving this formula for the various ITIs in Experiment 1 with the independent schedules indicates that as the duration of the ITIs increased, the probability of reinforcement also increased on each schedule, such that with long ITIs the probability was high that reinforcement was available for a response to either schedule. Thus, the effective relative rate of reinforcement on independent schedules decreased from .75 toward .50 as ITI increased. In contrast, with interdependent schedules, the effective relative rate of reinforcement remained at approximately .75 regardless of the length of the ITI. With both schedule types, then, it can be said that choice responding conformed to the probability of reinforcement that actually influ-

Table 4

Changeover probabilities for runs of up to five responses for each bird in Experiment 2. The data in this table include the duration of the ITI (in seconds), whether the schedules were independent (ind) or interdependent (int), whether the level of analysis was based on runs calculated on an overall basis or postreinforcement, the relative response and reinforcement rates (expressed in terms of the A schedule), and the changeover probabilities. In Experiment 2, the A schedule is one VI 1.5-min schedule, and the B schedule is the other VI 1.5-min schedule.

Bird	ITI	Schedule type	Level of analysis	Relative rate		Changeover probability									
				Re-spon-ses	Rein-forcement	A → B					B → A				
						1	2	3	4	5	1	2	3	4	5
R-1	0 s	Ind	Overall	.52	.50	.85	.91	.90			.94	.96			
		Ind	Post			.41	.83				.67	.90	.50		
		Int	Overall	.53	.50	.73	.61	.64	.53	.55	.81	.69	.48	.56	.57
	6 s	Ind	Post			.13	.65	.88	.50		.90	.83			
		Ind	Overall	.50	.49	.66	.79	.71	.80		.69	.76	.67	.17	.80
		Ind	Post			.58	.92				.66	.86	.67		
	22 s	Int	Overall	.50	.50	.70	.69	.81	.25	.33	.52	.63	.63	.53	.57
		Int	Post			.80	.83				.30	.60	.53	.50	
		Ind	Overall	.51	.51	.48	.47	.52	.36	.14	.57	.47	.32	.62	.20
	120 s	Ind	Post			.54	.46	.38	.50		.53	.67	.50	.50	
		Int	Overall	.48	.50	.56	.47	.55	.54	.50	.53	.57	.64	.33	.17
		Int	Post			.49	.47	.54			.42	.66	.75		
	120 s	Ind	Overall	.53	.53	.44	.46	.67	.60		.59	.57	.33	.33	.50
		Ind	Post			.50	.45				.51	.57	.33		
		Int	Overall	.47	.50	.51	.52	.50	.70	.67	.49	.47	.48	.42	.57
		Int	Post			.50	.61	.75	.50		.45	.47	.78	0	.50
R-5	0 s	Ind	Overall	.53	.50	.80	.76	.44	.20	.50	.86	.88			
		Ind	Post												
		Int	Overall	.57	.51	.72	.67	.51	.53	.38	.81	.68	.64	.50	.50
	6 s	Ind	Post			.79	.38	0	0	.25	.66	.70	.83		
		Ind	Overall	.50	.49	.51	.63	.69	.67	.33	.52	.59	.66	.73	.67
		Ind	Post			.66	.65	.50			.38	.51	.79		
	22 s	Int	Overall	.49	.50	.63	.58	.60	.75	.67	.56	.67	.64	.30	.71
		Int	Post			.56	.35	.56	.67	.50	.48	.65	.50	.50	.50
		Ind	Overall	.53	.52	.54	.49	.47	.30	.14	.64	.45	.56	.14	.17
	120 s	Ind	Post			.48	.39	.17	.50	.50	.56	.40	.46	.25	.33
		Int	Overall	.52	.50	.46	.62	.72	.86		.57	.65	.56	.63	
		Int	Post			.45	.66	.78			.54	.67	.50	.67	
	120 s	Ind	Overall	.45	.47	.57	.42	.36	.28	.60	.45	.33	.31	.64	.50
		Ind	Post			.47	.48	.50			.45	.33	.33		
		Int	Overall	.50	.50	.54	.36	.48	.36		.58	.44	.27	.38	.70
		Int	Post			.59	.57	.29	.20	.25	.50	.37	.30	.57	.67
R-6	0 s	Ind	Overall	.47	.50	.84	.87	.75	.50		.80	.64	.45	.63	.33
		Ind	Post			.81	.91				.62	.87	.67		
		Int	Overall	.42	.50	.84	.59	.38	.30	.29	.76	.71	.18	.21	.09
	6 s	Ind	Post			.71	.53	.29	.50	0	.33	.64	.15	.09	.13
		Ind	Overall	.44	.46	.55	.65	.63	.44	.20	.49	.49	.32	.37	.47
		Ind	Post			.42	.72	.44	.60	.50	.42	.57	.29	.56	.25
	22 s	Int	Overall	.50	.50	.86	.85	.71			.86	.85	.71		
		Int	Post			.72	.82	.33			.66	.80	.67		
		Ind	Overall	.48	.48	.48	.32	.52	.09	.40	.54	.33	.15	.06	.31
	120 s	Ind	Post			.44	.31	.32	0	.38	.48	.19	.19	.14	.14
		Int	Overall	.50	.50	.46	.54	.46	.27	.36	.46	.49	.58	.23	.20
		Int	Post			.61	.57	.46	.40	.50	.48	.29	.38	.22	0
	120 s	Ind	Overall	.48	.48	.54	.48	.36	.29	.40	.47	.38	.40	.11	.50
		Ind	Post			.54	.31	.20			.48	.31	.28		
		Int	Overall	.51	.50	.48	.45	.38	.40	.33	.49	.35	.54	.54	.50
		Int	Post			.46	.41	.38	.40	.33	.52	.34	.50		

Table 4

(Continued)

Bird	ITI	Schedule type	Level of analysis	Relative rate		Changeover probability									
				Re-spon-ses	Rein-forcement	A → B					B → A				
						1	2	3	4	5	1	2	3	4	5
R-7	0 s	Ind	Overall	.53	.51	.62	.72	.63	.42	.36	.70	.75	.70	.64	.50
		Ind	Post			.31	.88	.40	.67		.67	.95			
		Int	Overall	.55	.50	.66	.62	.62	.56	.82	.78	.80	.87	.67	
		Int	Post			.18	.86	.71	.50		.66	.95			
	6 s	Ind	Overall	.48	.51	.66	.57	.57	.50	.80	.56	.67	.39	.50	.71
		Ind	Post			.54	.52	.50	.80		.47	.67	.56	.33	.50
		Int	Overall	.49	.50	.75	.65	.35	.62		.74	.55	.67	.50	.25
		Int	Post			.60	.75	.83			.63	.73	.67		
	22 s	Ind	Overall	.56	.52	.41	.55	.38	.23	.40	.59	.48	.47	.44	.40
		Ind	Post			.39	.40	.35	.13	.50	.57	.52	.52	.33	.50
		Int	Overall	.56	.52	.40	.29	.20	.32	.37	.47	.48	.43	.23	.50
		Int	Post			.44	.24	.33	.13	.14	.36	.53	.38	.57	.0
	120 s	Ind	Overall	.61	.57	.41	.33	.39	.18	.67	.67	.47	.63	.33	
		Ind	Post			.40	.36	.50			.65	.47			
		Int	Overall	.54	.49	.43	.49	.27	.44	.56	.56	.48	.24	.38	.88
		Int	Post			.51	.35	.27	.57	.67	.58	.39	.43	.67	
R-8	0 s	Ind	Overall	.52	.50	.89	.87	.90			.95	.97			
		Ind	Post			.71					.67	.95			
		Int	Overall	.54	.50	.75	.80	.81	.50	.0	.89	.99			
		Int	Post			.40	.94				.68				
	6 s	Ind	Overall	.51	.50	.77	.78	.69	.50	.50	.83	.70	.77	0	.67
		Ind	Post			.46	.88	.50			.65	.81			
		Int	Overall	.53	.50	.53	.44	.47	.46	.46	.55	.54	.42	.33	.29
		Int	Post			.37	.53	.31	.44	.40	.53	.56	.40	.60	0
	22 s	Ind	Overall	.32	.33	.54	.58	.20	.38	.60	.40	.48	.50	.25	.33
		Ind	Post			.49	.40	.33	0	.67	.38	.36	.43	.33	.33
		Int	Overall	.55	.50	.42	.63	.52	.23	.40	.54	.68	.55	.50	.50
		Int	Post			.35	.64	.67	0	0	.56	.81	.80		
	120 s	Ind	Overall	.54	.54	.45	.35	.07	.36	.44	.56	.42	.09	.40	.33
		Ind	Post			.41	.39	0			.45	.43	.29		
		Int	Overall	.52	.50	.54	.36	.30	.31	.09	.51	.41	.48	.33	.63
		Int	Post			.54	.22	.22	.57	.33	.60	.46	.17	.60	.50
R-9	0 s	Ind	Overall	.48	.51	.90	.95	.50			.84	.83	.75		
		Ind	Post			.70					.61	.91	.50	.71	
		Int	Overall	.48	.50	.80	.74	.64	.38	.80	.72	.74	.39	.63	.71
		Int	Post			.54	.77	.40	.67		.52	.83	.40	.67	
	6 s	Ind	Overall	.54	.51	.72	.64	.78	.40	1.0	.82	.78	.89		
		Ind	Post			.70	.76	.75			.69	.89			
		Int	Overall	.52	.50	.71	.65	.57	.30	.71	.73	.79	.77	.33	.50
		Int	Post			.63	.71	.60	.50		.61	.87	.33	.50	
	22 s	Ind	Overall	.51	.51	.55	.39	.45	.42	.29	.51	.53	.47	.20	.63
		Ind	Post			.54	.46	.50	.40	.50	.53	.48	.52	.50	
		Int	Overall	.48	.50	.58	.47	.35	.24	.54	.57	.47	.54	.17	1.0
		Int	Post			.53	.50	.25	.22	.57	.61	.30	.50	.17	0
	120 s	Ind	Overall	.55	.54	.34	.52	.54	.17	.20	.54	.42	.45	0	.67
		Ind	Post			.42	.35	.67			.47	.28	1.0		
		Int	Overall	.46	.50	.46	.51	.57	.67		.41	.38	.55	.46	.71
		Int	Post			.45	.52	.50	.80		.44	.39	.46	.57	.67

enced the animals, rather than the mean interreinforcement interval on each schedule.

The accompanying question is why didn't lengthening the ITIs disrupt the control of sequences of responding, as revealed in the

changeover probabilities? Perhaps the answer lies in certain details of the discrete-trial procedure itself. Silberberg and Williams (1974) suggested that the lights-off/lights-on sequence of the discrete-trial procedure may

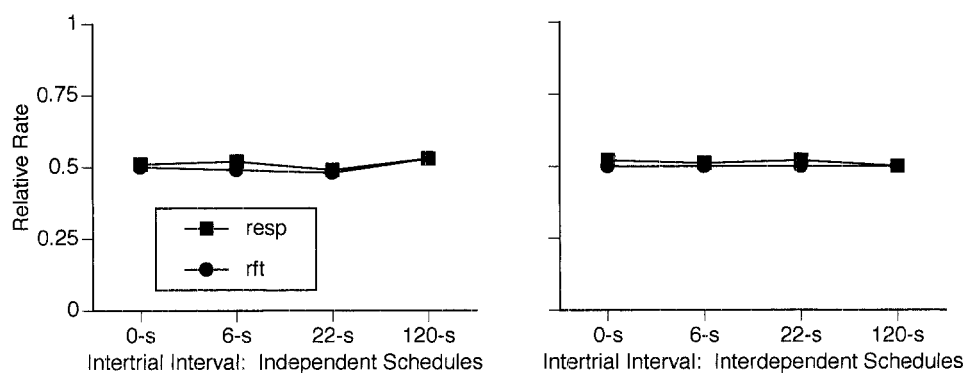


Fig. 4. Average relative response and reinforcement rates in Experiment 2.

have maximized the salience of certain environmental circumstances, particularly the transition from (a) the absence of reinforcement associated with dark keys to (b) the presence of reinforcement associated with lighted keys. One possibility is that such a sequence of events interferes with discrimination of the local reinforcement contingencies. The implication is that the variables that affect choice in discrete-trial procedures differ from those that affect choice in free-operant procedures. Although Williams (1992) considered but then discounted this possibility, he did emphasize the relatively poor discrimination of local reinforcement probabilities in his research. The interference may be the reason for the poor discrimination. In any case, if this possibility is extended a bit

further, the dynamics of the discrete-trial procedure may actually have more in common with the concurrent-chains procedure than the simple concurrents procedure. Each has a discriminable period in which reinforcement is not available (concurrent chains: initial links; discrete trials: ITI), followed by transition to a discriminable period in which reinforcement is available (concurrent chains: terminal links; discrete trials: during a trial). Perhaps the sequential dependencies proposed by molecular theories may not develop in a discrete-trial procedure because of these repeated transitions, whereas they may well develop on free-operant concurrent VI VI. Thus, it may be that the discrete-trial procedure and the free-operant procedure are in some sense fundamentally different. In this

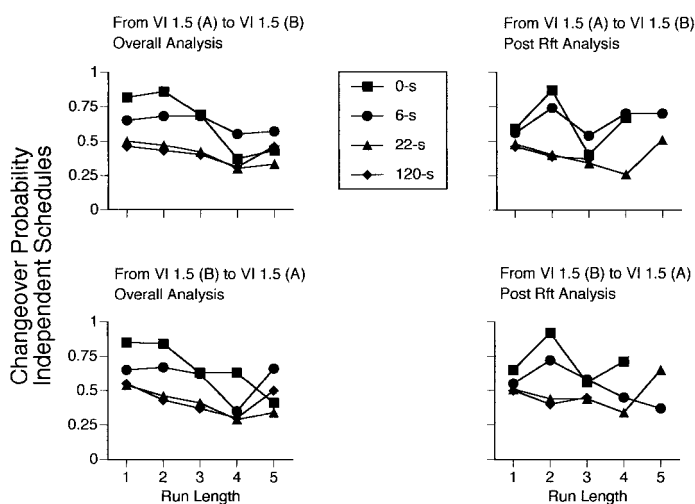


Fig. 5. Average changeover probabilities as a function of run length for independent schedules in Experiment 2.

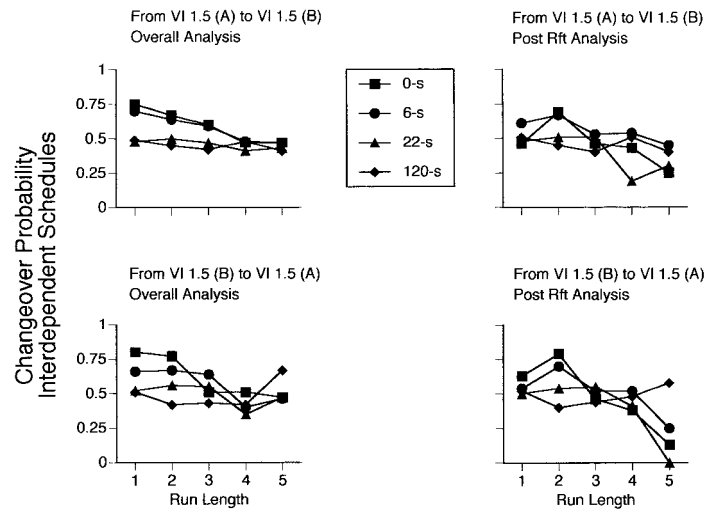


Fig. 6. Average changeover probabilities as a function of run length for interdependent schedules in Experiment 2.

regard, response-based schedules, such as the probability learning studies mentioned earlier (e.g., Silberberg & Williams, 1974; Williams, 1992), may be better to use than time-based schedules in discrete-trial manipulations because the response-based schedules do not involve the same kind of shift in absolute and relative reinforcement probabilities across time that occurs with time-based schedules.

A further consideration is that discrimination of the locus of the prior response in a two-response situation may be subtle. Roberts (1972) has shown that increasing the response requirement, say from 1 to 5 to 15 responses, will increase accuracy in a delayed conditional discrimination procedure, presumably because the increased response requirement increases discriminative control by relevant features of the task. It is conceivable that the present discrete-trial procedure, which required four responses to initiate access to a schedule and then one response on the schedule itself, acted similarly and promoted control by the overall reinforcement rate, at the expense of local factors. Thus, not only might discrete-trial choice procedures function differently from free-operant choice procedures, but the present version of a discrete-trial procedure may function differently from the conventional version of a discrete-trial procedure, such as Nevin's (1969), because of the added response requirements.

Three further findings are of interest. The

first is that the perseveration noted in both experiments (see changeover functions with slightly negative slopes in Figures 2, 3, 5, and 6) can be construed as a kind of local control. In this kind of control, the locus of the response on trial N exerts discriminative control on trial $N + 1$, such that the subject selects the same key again, without apparent regard for either the local or overall probability of reinforcement. Perhaps this kind of local control arises from phylogenetic considerations rather than from reinforcement parameters experienced during the experimental sessions. In any event, this kind of local control was in evidence, even when one response was separated from the next by an ITI of 120 s.

The second finding of interest is that the choice and changeover data tended to be much the same on interdependent as on independent schedules. This finding should put to rest experimenters' concerns that the interdependent procedure forces a subject to do what it would not otherwise do. Although the data were variable, the conservative conclusion is that there is no evidence that the interdependent schedules biased the responding in any way.

The third finding of interest is that the changeover data tended to be much the same on a postreinforcement analysis as on an overall level of analysis. A particular finding in this regard is that subjects were about as

likely to stay as switch after reinforcement. As noted in the General Method section above, the present VI schedules were based on the Catania and Reynolds (1968) equation. Schedules of this sort are often designated as *constant probability* schedules. Unlike an arithmetic or geometric schedule, in which reinforcement availability changes across time, a constant probability schedule means that, given relatively consistent responding, reinforcement is just as likely to be gained a few seconds as many seconds after the last reinforcement. Indeed, Catania and Reynolds observed differential responding as a function of the passage of time with arithmetic schedules but not with constant probability schedules. In the present research, then, the time immediately after a reinforcer was not temporally discriminated as a time when reinforcement was unavailable, as would be evidenced by a higher probability of postreinforcement switching. In addition, the birds did not exhibit a win-stay pattern and repeat the just-reinforced response, as would be evidenced by a lower probability of postreinforcement switching (cf. Williams, 1992). To be certain, there were instances of perseveration, but they were not part of a win-stay pattern.

In conclusion, these two experiments investigated the distribution and dynamics of responding on discrete-trial concurrent VI VI procedures with increasing ITIs. Changeover probabilities on runs of up to five responses run were mixed, with no evidence of any systematically increasing changeover probability at any ITI or a trend toward chance responding as the duration of ITIs increased. Overall, the present changeover data were not consistent with the most frequently expressed predictions based on discriminations of the local probability of reinforcement.

REFERENCES

- Baum, W. M. (1979). Matching, undermatching, and overmatching in studies of choice. *Journal of the Experimental Analysis of Behavior*, 32, 269–281.
- Baum, W. M. (1981). Optimization and the matching law as accounts of instrumental behavior. *Journal of the Experimental Analysis of Behavior*, 36, 387–403.
- Catania, A. C., & Reynolds, G. S. (1968). A quantitative analysis of responding maintained by interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 11, 327–383.
- deVilliers, P. (1977). Choice in concurrent schedules and a quantitative formulation of the law of effect. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 233–287). Englewood Cliffs, NJ: Prentice Hall.
- Fetterman, J. G., & Stubbs, D. A. (1982). Matching, maximizing, and the behavioral unit: Concurrent reinforcement of response sequences. *Journal of the Experimental Analysis of Behavior*, 37, 97–114.
- Herrnstein, R. J. (1961). Relative and absolute strength of response as a function of frequency of reinforcement. *Journal of the Experimental Analysis of Behavior*, 4, 267–272.
- Herrnstein, R. J. (1970). On the law of effect. *Journal of the Experimental Analysis of Behavior*, 13, 243–266.
- Herrnstein, R. J., & Vaughan, W. (1980). Melioration and behavioral allocation. In J. E. R. Staddon (Ed.), *Limits to action: The allocation of individual behavior* (pp. 143–176). New York: Academic Press.
- Heyman, G. M. (1979). A Markov model description of changeover probabilities on concurrent variable-interval schedules. *Journal of the Experimental Analysis of Behavior*, 31, 41–51.
- Hinson, J., & Staddon, J. E. R. (1983). Hill-climbing by pigeons. *Journal of the Experimental Analysis of Behavior*, 39, 25–47.
- Mazur, J. (1981). Optimization theory fails to predict performance of pigeons in a two-response situation. *Science*, 214, 823–825.
- Millenson, J. (1963). Random interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 6, 437–443.
- Mohr, S. E. (1976). *An experimental investigation of two models of choice behavior*. Unpublished doctoral dissertation, American University.
- Nevin, J. A. (1969). Interval reinforcement of choice behavior in discrete trials. *Journal of the Experimental Analysis of Behavior*, 12, 875–885.
- Nevin, J. A. (1979). Overall matching vs. momentary maximizing: Nevin (1969) revisited. *Journal of Experimental Psychology: Animal Behavior Processes*, 5, 300–306.
- Roberts, W. A. (1972). Short-term memory in the pigeon: Effects of repetition and spacing. *Journal of Experimental Psychology*, 94, 74–83.
- Shimp, C. P. (1966). Probabilistically reinforced choice behavior in pigeons. *Journal of the Experimental Analysis of Behavior*, 9, 433–455.
- Shimp, C. P. (1982). Choice and behavioral patterning. *Journal of the Experimental Analysis of Behavior*, 37, 157–169.
- Silberberg, A., Hamilton, B., Ziriox, J. M., & Casey, J. (1978). The structure of choice. *Journal of Experimental Psychology: Animal Behavior Processes*, 4, 368–398.
- Silberberg, A., & Williams, D. (1974). Choice behavior on discrete trials: A demonstration of the occurrence of a response strategy. *Journal of the Experimental Analysis of Behavior*, 21, 315–322.
- Silberberg, A., & Ziriox, J. M. (1982). The interchange-over time as a molecular dependent variable in concurrent schedules. In M. L. Commons, R. J. Herrnstein, & H. Rachlin (Eds.), *Quantitative analyses of behavior: Vol. 2. Matching and maximizing accounts* (pp. 131–151). Cambridge, MA: Ballinger.
- Stubbs, D. A., & Pliskoff, S. S. (1969). Concurrent responding with fixed relative rate of reinforcement. *Journal of the Experimental Analysis of Behavior*, 12, 887–895.

- Vaughan, W. (1981). Melioration, matching, and maximization. *Journal of the Experimental Analysis of Behavior*, 36, 141–149.
- Weisman, R. G., Dodd, P. W. D., Wasserman, E. A., & Larew, M. B. (1980). Representation and retention of two-event sequences in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, 6, 312–325.
- Williams, B. A. (1983). Effects of intertrial interval on momentary maximizing. *Behaviour Analysis Letters*, 3, 35–42.
- Williams, B. A. (1985). Choice behavior in a discrete-trial concurrent VI-VR: A test of maximizing theories of matching. *Learning and Motivation*, 16, 423–443.
- Williams, B. A. (1988). Reinforcement, choice and response strength. In R. C. Atkinson, R. J. Herrnstein, G. Lindzey, & R. D. Luce (Eds.), *Stevens' handbook of experimental psychology* (2nd ed., pp. 167–244). New York: Wiley.
- Williams, B. A. (1991). Choice as a function of local versus molar reinforcement contingencies. *Journal of the Experimental Analysis of Behavior*, 56, 455–473.
- Williams, B. A. (1992). Dissociation of theories of choice by temporal spacing of choice opportunities. *Journal of Experimental Psychology: Animal Behavior Processes*, 18, 287–297.

Received August 18, 1997
Final acceptance January 5, 1999